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ONR ANNUAL PRODUCTIVITY STATISTICS  
 ON ONR GRANT NO. N00014-92-J-1587  
 TO UNIVERSITY OF WASHINGTON  
 FOR CALENDAR YEAR 1993  
 (Project 1 of 2)

1. **Principal investigator(s):**  
 Peter V. Hobbs

2. **Title, funding level, and duration of funded proposal.**  
 "Studies of Marine Aerosols and Their Evolution in the Eastern North Atlantic"  
 \$206,513  
 15 April 1992 through 30 September 1995

3. **Total papers submitted and/or published in refereed journals.**  
 Please also submit copies of papers or abstracts.

- 1) "Aerosol Size Distributions in the Cloudy Atmospheric Boundary Layer of the North Atlantic Ocean" by D. A. Hegg, R. J. Ferek and P. V. Hobbs. J. Geophys. Res., 98, 8841 (1993).
- 2) "Light Scattering and Cloud Condensation Nucleus Activity of Sulfate Aerosol Measured Over the Northeast Atlantic Ocean" by D. A. Hegg, R. J. Ferek and P. V. Hobbs. J. Geophys. Res., 98, 14,887 (1993).

4. **Total papers scheduled to be published at a later date in refereed journals.** Identify also the tentative titles, authors, and, if possible, abstracts.

Probably 2 papers on marine cloud microstructures and their susceptibility to modification by pollutants.

5. **Total papers published or accepted in non-refereed journals.**  
 Please provide titles and abstracts.

"The Structure of Frontal Weather Systems in Western Europe" by P. V. Hobbs.  
ESN Information Bulletin, 1994 (in press).

6. **Number of Technical Reports.** List the titles and abstracts.  
 (Data collected aboard our C-131A research aircraft has been provided to the ASTEX archives)

7. **Number of Books published.** List the titles and abstracts.  
"Aerosol-Cloud-Climate Interactions" Edited by Peter V. Hobbs, Academic Press 1993, pp. 233.

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94-1-24 075

**8. Number of book chapters published, other than in #5. List the titles and abstracts.**

- 1) "Aerosol-Cloud-Climate Interactions" by Peter V. Hobbs (Chapt. 2 in book listed in #7).
- 2) "Recent Field Studies of Sulfur Gases, Particles and Cloud in Clean Marine Air and their Significance with Respect to the DMS-Cloud-Climate Hypothesis" by P. V. Hobbs, D. A. Hegg and R. J. Ferek. In Dimethyl Sulphide: Oceans, Atmosphere and Climate, Ed. G. Restelli and G. Angelletti, Kluwer Pub. (1993).

**9. Number of patent applications. Include patent application number and/or patent numbers.**

0

**10. Number of significant presentations:**

Forum, date and title of the most significant. For each of the three most significant presentations, please include no more than a few sentences describing its significance.

"Recent Field Studies of Aerosol and Cloud Processes Relevant to Climate" by P. V. Hobbs, IAMAS Intern. Cloud-Radiation Workshop, Camp Springs, Maryland, 18-20 Oct. 1993.

**11. Honors and awards received by principal investigators. Please include title, recipient, and date. Underline those that were the result of ONR funding.**

- 1) Peter V. Hobbs, Elected Fellow of American Geophysical Union, 12/93
- 2) " " " , Appointed Chairman of the Scientific Steering Committee for the International Global Aerosol Program (IGAP)

**12. Total number of different post-docs supported at least 25% of the time.**

0

**13. Number of different graduate students supported at least 25% of the time.**

1. Timothy Garrett from 9/16/93 through current

**14. List the most significant publications n name, volume, number, page) and up to ten lines why the publication is truly significant.**

See # 7. This book, edited by Peter V. Hobbs, provides a review of current knowledge of aerosol-cloud-climate interactions.

**15. Major Accomplishments, organized by objective, of your funded research in (five to six succinct lines of text in a paragraph, include specific references, where possible).**

Acquisition of very good data sets on aerosols and clouds in the vicinity of the Azores as part of ASTEX

**16. Significant transitions; if any follow-on research has begun or been proposed, identify the sponsor, funding level, and contact person (phone number) who can provide additional information.**

Sponsor:

Funding level: (\$ in FY XX)

Sponsor Phone number for additional information:

**17. Impact of your research. In particular, identify new research areas identified and/or stimulated and/or accomplishments other than those listed above.**

Our measurement of the direct and indirect effects of aerosols on solar radiation (obtained in ASTEX) show that recent estimates of the effects of aerosols on climate contain large uncertainties.

**18. Key words describing research.**

marine aerosols

marine clouds

**19. Key words describing technologies impacted by your research.**

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AEROSOL SIZE DISTRIBUTIONS IN THE CLOUDY ATMOSPHERIC  
BOUNDARY LAYER OF THE NORTH ATLANTIC OCEAN

Dean A. Hegg, Ronald J. Ferek, and Peter V. Hobbs

Department of Atmospheric Sciences, University of Washington, Seattle

**Abstract.** Measurements are presented of the size distribution and volatility of particles in the cloudy atmospheric boundary layer of the North Atlantic Ocean. The results suggest that particle nucleation of acid sulfates commonly occurs but is neither spatially nor temporally homogeneous. Such nucleation appears to be inversely correlated with preexisting particle surface area. The few measurements obtained in clouds show a different acid sulfate distribution from those in clear air.

LIGHT SCATTERING AND CLOUD CONDENSATION NUCLEUS ACTIVITY OF  
SULFATE AEROSOL MEASURED OVER THE NORTHEAST ATLANTIC OCEAN

Dean A. Hegg, Ronald J. Ferek, and Peter V. Hobbs

Department of Atmospheric Sciences, University of Washington, Seattle

**Abstract.** Measurements on the relationship between sulfate mass and light scattering coefficient, and sulfate cloud condensation nucleus efficiency over the Northeast Atlantic Ocean suggest lower values for these parameters than have been used in recent estimates of the climatic impact of sulfate aerosols. Analysis suggests an important role in both processes for non-sulfate aerosol.

# Aerosol-Cloud-Climate Interactions

Edited by

*Peter V. Hobbs*

DEPARTMENT OF ATMOSPHERIC SCIENCES  
UNIVERSITY OF WASHINGTON  
SEATTLE, WASHINGTON



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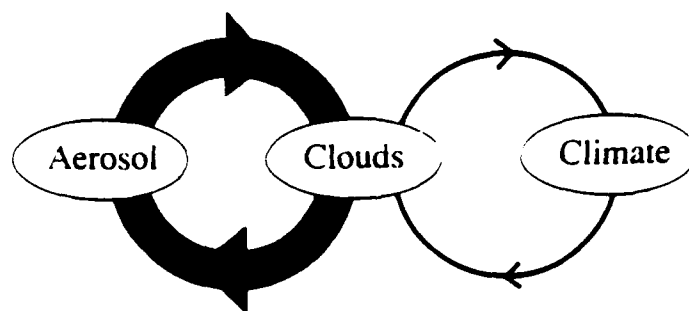
Harcourt Brace & Company

San Diego New York Boston

London Sydney Tokyo Toronto

## Preface

Together with molecular scattering from gases, aerosol and clouds determine what fraction of the solar radiation incident at the top of the atmosphere reaches the earth's surface, and what fraction of the longwave radiation from the earth escapes to space. Consequently, aerosol and clouds play an important role in determining the earth's climate. Much remains to be learned about the properties of atmospheric aerosol and clouds and their effects on the radiative balance of the earth. The problem stems, in part at least, from the fact that unlike gases, aerosol and clouds are distributed very unevenly in the atmosphere. Also, many of the relevant properties of aerosol and clouds are not well defined. Finally, there are strong interactions between aerosol, clouds, and climate (see the accompanying figure), many of which we are only just beginning to understand, let alone incorporate into climate models.



This book provides an overview of our present understanding of atmospheric aerosol and clouds, of the six potential interactions indicated in the figure, and of the outstanding problems that remain to be solved if we are to understand this complex system in both its natural and (anthropogenically) perturbed state. The first chapter reviews the sources, sinks, and properties of atmospheric aerosol. In the second chapter the effects of aerosol on clouds, and the effect of clouds on aerosol, are described. Chapter 3 is concerned with the direct effects of aerosol on the radiation balance of the earth and climate. A review of the principal forms of clouds, and their microstructures, is presented in Chapter 4. This is followed, in Chapters 5 and 6, by reviews of the radiative properties of clouds and the current understanding of the effects of clouds on the radiative balance of the earth. Chapter 7 provides an account of recent attempts to include fairly detailed information on clouds in operational numerical prediction models and general circulation models. The book concludes with a discussion of stratospheric aerosol and clouds.

The framework for this book was conceived at the XX Assembly of the International Union of Geodesy and Geophysics, Vienna, Austria, 13–20 August 1991. I am grateful to the authors for their willingness to expand considerably on the scope of their original presentations in order to provide the comprehensive description of the subject that is contained in this book.

Peter V. Hobbs



## Chapter 2

## Aerosol-Cloud Interactions

**Peter V. Hobbs**

Atmospheric Sciences Department  
University of Washington  
Seattle, Washington

Aerosol-cloud-climate interactions involve the six interactions depicted schematically in the preface to this book. This chapter is concerned with a review of two of these interactions: the effects of atmospheric aerosol on clouds, and the effects of clouds on atmospheric aerosol. The discussion is confined to tropospheric clouds; aerosol-cloud interactions in the stratosphere are discussed in Chapter 8.

Various aspects of the effects of aerosol on clouds have been studied for many years. This is because the aerosol on which cloud droplets form determine the initial concentrations and sizes of the droplets. Aerosol may also play a role in the formation of ice in clouds. Thus, through their effects on both the nature (water or ice) and the size distribution of cloud particles, aerosol can play a role in determining whether or not clouds precipitate and the radiative properties of clouds. These topics are reviewed in the first part of this chapter.

Clouds and precipitation are important sinks for atmospheric aerosol. This affects both the size distribution and chemical nature of atmospheric aerosol, as well as the chemical composition of clouds and precipitation. In addition to modifying existing aerosol, some recent research indicates that clouds can be involved in the nucleation of new aerosol. These topics form the subject of the second part of this chapter.

Recent Field Studies of Sulfur Gases, Particles and Clouds in Clean Marine Air and their  
Significance with Respect to the DMS-Cloud-Climate Hypothesis

by

Peter V. Hobbs, Dean A. Hegg, and Ronald J. Ferek

*Atmospheric Sciences Department, University of Washington, Seattle, WA 98195*

SUMMARY

Airborne measurements have been made of the vertical profiles of dimethylsulfide (DMS), SO<sub>2</sub> (in the sub- 100 pptv range), particle concentrations and size spectra, non-sea-salt (NSS) sulfate, and cloud condensation nucleus (CCN) spectra during conditions of clean marine airflow over the northeastern Pacific Ocean. More limited measurements have also been obtained over the Arctic Ocean.

DMS concentrations in the marine boundary layer over the Pacific Ocean varied seasonally from as little as a few to several hundred pptv and tended to decrease from the surface up to the top of the marine boundary layer. DMS concentrations over the Arctic Ocean ranged from a few pptv in early June to  $\approx$  300 pptv later in the month; the latter concentration is among the highest ever measured. The concentrations of DMS were large enough to account for most of the measured SO<sub>2</sub> and NSS sulfate.

DMS and CCN are correlated, but not by the same linear relation at all supersaturations. Cases of new particle production, in and around clouds, have been documented. We attribute this to the homogeneous-biomolecular oxidation of SO<sub>2</sub>.

The significance of these new data to the DMS-cloud-climate hypothesis is discussed.

IAMAS International Cloud-Radiation Workshop  
NOAA, Camp Springs, MD, 18-20 October 1993

**Recent Field Studies of Aerosol and Cloud Processes Relevant to Climate**

by

**Peter V. Hobbs**

*Atmospheric Sciences Department, University of Washington, Seattle, WA 98195*

**SUMMARY**

Aerosols have the potential to change the radiative balance of the earth by directly scattering solar radiation back into space and, indirectly, by acting as cloud condensation nuclei (CCN) and changing the radiative properties of clouds. Although some estimates have been made of the direct and indirect effects of anthropogenic sulfate, more information is needed on their worldwide distribution and properties to determine their effects on climate. Recent measurements on the light-scattering efficient of sulfate over the Northern Atlantic Ocean give lower values than those over land, which were used in the estimates of the direct effects of anthropogenic sulfate on climate. Also, during the period of measurements over the Atlantic Ocean, sulfate was not the dominant constituent of the aerosols. The geographical variations in the CCN efficiency of sulfate also need to be known in order to estimate the indirect effects of anthropogenic sulfate on climate. Some values of the CCN efficiencies of sulfate over the Atlantic Ocean will be presented.

ONR ANNUAL PRODUCTIVITY STATISTICS  
ON ONR GRANT NO. N00014-92-J-1587  
TO UNIVERSITY OF WASHINGTON  
FOR CALENDAR YEAR 1993  
(Project 2 of 2)

**1. Principal investigator(s):**

Peter V. Hobbs and Dean A. Hegg for first award

Ronald J. Ferek, Dean A. Hegg, Alan P. Waggoner and Peter V. Hobbs for second award

**2. Title, funding level, and duration of funded proposal.**

"Studies of Marine Aerosols and Their Evolution in the Eastern North Atlantic"  
15 April 1992 through 14 April 1995  
\$90,272

"Airborne Studies of Ship Tracks"  
15 April 1992 through 30 September 1995  
\$202,754 plus \$249,204 contingent upon availability of funds

**3. Total papers submitted and/or published in refereed journals.**

Please also submit copies of papers or abstracts.

"A Reassessment of the Bistability of Cloud Condensation Nucleus Concentrations." A. S. Ackerman, O. B. Toon and P. V. Hobbs  
(Nature, in press).

**4. Total papers scheduled to be published at a later date in refereed journals.** Identify also the tentative titles, authors, and, if possible, abstracts.

"In-situ Measurements of Ship-Induced Cloud Tracks." R. J. Ferek, P. Durkee, D. A. Hegg and P. V. Hobbs (to be submitted to J. Geophys. Res.).

**5. Total papers published or accepted in non-refereed journals.**

Please provide titles and abstracts.

"Dimethyl Sulfide: Oceans, Atmosphere, and Climate." Peter V. Hobbs. ESN Information Bulletin, 93-06 (1993).

**6. Number of Technical Reports.** List the titles and abstracts.

0

**7. Number of Books published .** List the titles and abstracts.

"Aerosol-Cloud-Climate Interactions" Edited by Peter V. Hobbs, Academic Press 1993, pp. 233.

**8. Number of book chapters published, other than in #5.** List the titles and abstracts.

- 1) "Aerosol-Cloud-Climate Interactions" by Peter V. Hobbs (Chapt. 2 in book listed in #7).
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**9. Number of patent applications.** Include patent application number and/or patent numbers.

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**10. Number of significant presentations:**

Forum, date and title of the most significant. For each of the three most significant presentations, please include no more than a few sentences describing its significance.

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**11. Honors and awards received by principal investigators.** Please include title, recipient, and date. Underline those that were the result of ONR funding.

- 1) Peter V. Hobbs, Elected Fellow of American Geophysical Union, 12/93
- 2) " " " , Appointed Chairman of the Scientific Steering Committee for the International Global Aerosol Program (IGAP)

**12. Total number of different post-docs supported at least 25% of the time.**

0

**13. Number of different graduate students supported at least 25% of the time.**

0

**14. List the most significant publications n name, volume, number, page) and up to ten lines why the publication is truly significant.**

See #7. This book, edited by Peter V. Hobbs, provides a comprehensive review of current knowledge of aerosol-cloud-climate interactions (including "ship-tracks").

**15. Major Accomplishments, organized by objective, of your funded research in (five to six succinct lines of text in a paragraph, include specific references, where possible).**

Analysis of one of the most complete *in situ* data sets on "ship-tracks" collected to date (see #4)

**16. Significant transitions; if any follow-on research has begun or been proposed, identify the sponsor, funding level, and contact person (phone number) who can provide additional information.**

Sponsor:

Funding level: (\$ in FY XX)

Sponsor Phone number for additional information:

**17. Impact of your research. In particular, identify new research areas identified and/or stimulated and/or accomplishments other than those listed above.**

NOTE: A major part of the research supported by this grant will not occur until June 1994, when the WESTEX field project will take place. We are currently preparing for that field project.

**18. Key words describing research.**

ship tracks  
cloud albedo

**19. Key words describing technologies impacted by your research.**

A REASSESSMENT OF THE BISTABILITY OF CLOUD CONDENSATION  
NUCLEUS CONCENTRATIONS

Andrew S. Ackerman<sup>\*,†</sup>, Owen B. Toon<sup>†</sup>, and Peter V. Hobbs<sup>\*</sup>

<sup>\*</sup> Department of Atmospheric Sciences, University of Washington,  
Seattle, Washington 98195, USA

<sup>†</sup> NASA Ames Research Center, Moffett Field, California 94035, USA

**Abstract.** Marine stratocumulus clouds play an important role in the earth's radiation budget. The albedo of these clouds depends on the cloud droplet size spectrum, and therefore, in part, on the population of cloud condensation nuclei (CCN). It has been postulated that a feedback loop between increased CCN concentrations and decreased drizzle gives rise to a bistable system, in which there are two equilibrium CCN concentration regimes. If correct, this hypothesis implies that a small increase in the production of CCN over the oceans could drastically increase the planetary albedo. Employing a more sophisticated model than that used previously, we find no evidence for such a bistability. Further, we find that the time scales involved in reaching equilibrium CCN concentration are so long that equilibrium states are unlikely to be attained.

# ENVIRONMENT

## Dimethylsulfide, Oceans, Atmosphere, and Climate—An International Symposium

by Peter V. Hobbs. Dr. Hobbs is with the Atmospheric Sciences Department, University of Washington, Seattle, and currently on study leave at the Institut FISBAT-C.N.R., Via de Castagnoli 1, 40126 Bologna, Italy).

**KEYWORDS:** dimethylsulfide; marine phytoplankton; "Gaia" hypothesis; cloud condensation nuclei; atmospheric chemistry

### INTRODUCTION

This international symposium in Belgrate, Italy (13-15 October 1992), brought together an unusually diverse group of scientists whose disciplines ranged from marine biology to atmospheric science and whose interests ranged from the microscopic (plankton) to the global (climate). While some of the papers presented at the symposium confirmed the adage that some may "see the world in a grain of sand," it also demonstrated the value, indeed the necessity, of interdisciplinary studies when dealing with many environmental issues.

### DIMETHYLSULFIDE — CLOUD — CLIMATE

The symposium was prompted by the hypothesis that emissions of dimethylsulfide (DMS) from marine phytoplankton play a role in modulating climate. The links in the hypothesis are as follows. Dimethylsulfide ( $\text{CH}_3\text{-S-CH}_3$ ) is produced by certain species of phytoplankton, and it enters the atmosphere as a gas. Through gas-to-particle chemical conversion processes, DMS is the major source of sulfate particles in clean marine air. These sulfate particles serve as cloud condensation nuclei (CCN). The more sulfate particles there are in the air, the more drops there will be in a cloud, and the more the cloud will reflect the sun's radiation back into space. (The most important clouds in this respect are marine stratus, because they cover large areas of the globe.) Now, suppose the Earth warms (as the result, for example, of the greenhouse effect), and suppose further that phytoplankton respond to this warming in such a way as to increase the emissions of DMS into the atmosphere. Then, through the linkages outlined above, this would lead to an increase in the amount of solar radiation reflected back into space, which would tend to offset any global warming. In this case, DMS would tend to act as a global "thermostat," helping to prevent perturbations in global temperature. The system would, in fact, be a perfect example of James Lovelock's "Gaia" hypothesis, whereby biological systems act according to Le Chatelier's principle by adjusting in such a way as to offset any changes imposed by an external agent.

The DMS-cloud-climate hypothesis has generated a considerable interest, as much because of the many questions it raises and research that it suggests as for its potential importance as a regulator of Earth's climate. For example, how do marine organisms produce DMS and what factors affect this production? What is the flux of DMS from the ocean to the atmosphere? How does this flux vary around the globe? What are the chemical and physical processes involved in the production of new sulfate particles from DMS in the atmosphere? What is the rate of this production, and how does it depend on the concentration of DMS in the air? How do CCN and cloud drop concentrations in marine air depend on DMS? How sensitive is the reflectivity of solar radiation by marine clouds to DMS emissions from the ocean? How sensitive is the climate of the earth to all of these factors?

These questions, and many more, were discussed at the symposium: some 50 invited and contributed papers were presented. They were grouped under the headings: Production by Marine Phytoplankton, Field Measurements, Atmospheric Chemistry, Gas-to-Particle Conversion and CCN Production, and Global Modeling and Climate Implications. The symposium finished with a round table discussion on Atmospheric Sulfur and Climate.

### CONCLUSION

Although it was clear that remarkable progress has been made in quite a short time on many issues relevant to the DMS-cloud-climate hypothesis, we are still far from being able to evaluate its validity. This will require carefully coordinated interdisciplinary laboratory, field, and numerical modeling studies. This symposium was a small, but important, step in the right direction.

The proceeding of the symposium will be published as a book. For further information contact: G. Restelli, CEC-Joint Research Centre, ISPRA (VA), Italy.



# Aerosol–Cloud–Climate Interactions

Edited by

*Peter V. Hobbs*

DEPARTMENT OF ATMOSPHERIC SCIENCES  
UNIVERSITY OF WASHINGTON  
SEATTLE, WASHINGTON



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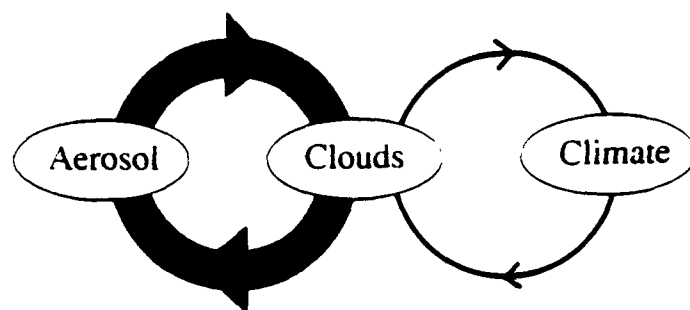
Harcourt Brace & Company

San Diego New York Boston

London Sydney Tokyo Toronto

## Preface

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**Peter V. Hobbs**

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References:

- 1) Hegg, D. A., R. J. Ferek and P. V. Hobbs. "Aerosol Size Distributions in the Cloudy Atmospheric Boundary Layer of the North Atlantic Ocean." J. Geophys. Res., **98**, 8841-8846.
- 2) Hegg, D. A., R. J. Ferek and P. V. Hobbs. "Light Scattering and Cloud Condensation Nucleus Activity of Sulfate Aerosol over the Northeast Atlantic Ocean." J. Geophys. Res., **98**, 14,887-14,894